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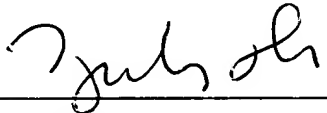
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I, Toyu Yazaki, hereby declare that I am a professional interpreter and translator, with twenty (20) years of professional experience, and am knowledgeable of and well acquainted with the Japanese language and the English language. The document attached hereto is to the best of my ability, knowledge and expertise a correct English translation of the original document written in the Japanese language.

I declare under penalty of perjury under the laws of the United States that the foregoing is true and correct. Executed this 18<sup>th</sup> day of May 2002 at San Francisco, California.



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(54) Title of the invention: Permanent magnet embedded rotor

(57) Abstract

**Problem:** The object is to make demagnetization less likely to occur in a rotor with permanent magnets.

**Means of solution:** Permanent magnets 8, 9 arranged in a radial direction of the rotor in multiple separated layers for each pole are embedded in rotor 13 made of a high permeable magnetic material. Each permanent magnet is shaped in an arc of which a convex side faces to the rotor center. A magnetic material with a high coercivity is used in only those portions where the magnetic flux density within the permanent magnets will be high when exposed to an opposing magnetic field from stator 2, thus providing a permanent magnet embedded rotor that is less susceptible to demagnetization and degradation of properties.

#### Claims

- Claim 1:** In a rotor with a plurality of sets of permanent magnets embedded therein with each pole having two or more separated layers disposed in a radial direction of the rotor, a permanent magnet embedded rotor characterized by each of the aforesaid permanent magnets having an arc-shape of which a convex side faces to the rotor center and the coercivity of the permanent magnets located closer to the outer periphery of the rotor in a multi-layer arrangement being higher than the coercivity of the permanent magnets located closer to the inner periphery of the rotor.
- Claim 2:** In a rotor with a plurality of sets of permanent magnets embedded therein with each pole having one or more separated layers disposed in a radial direction of the rotor, a permanent magnet embedded rotor characterized by each of the aforesaid permanent magnets having an arc-shape of which a convex side faces to the rotor center and, for each permanent magnet, the coercivity along the outer peripheral surface being higher than the coercivity along the inner peripheral surface.
- Claim 3:** In a rotor with a plurality of sets of permanent magnets embedded therein with each pole having one or more separated layers disposed in a radial direction of the rotor, a permanent magnet embedded rotor characterized by each of the aforesaid permanent magnets having an arc-shape of which a convex side faces to the rotor center and, for each permanent magnet, the coercivity at the two ends being higher than the coercivity at the centers.
- Claim 4:** In a rotor with a plurality of sets of permanent magnets embedded therein with each pole having two or more separated layers disposed in a radial direction of the rotor, a permanent magnet embedded rotor characterized by each of the aforesaid permanent magnets having an arc-shape of which a convex side faces to the rotor center, each permanent magnet having a coercivity that is higher at the two ends than at the centers, and, in a multi-layer arrangement of permanent magnets, the coercivity of the permanent magnets located closer to the outer periphery of the rotor being higher than the coercivity of the permanent magnets located closer to the inner periphery of the rotor.
- Claim 5:** A permanent magnet embedded rotor described in any of claims 1 through 4 wherein the shape of the embedded permanent magnets is an arc.

#### Detailed Description of the Invention

##### Technical Field to Which the Invention Pertains

The present invention relates to a permanent magnet embedded rotor with a plurality of sets of permanent magnets that are embedded in the rotor, the said plurality of sets of permanent magnets being disposed as multiple layers of inner and outer permanent magnets.

## Prior Art

A known prior art with rotors used in motors are rotors made of iron and other high permeable magnetic materials embedded with permanent magnets.

Fig. 5 shows a rotor of the prior art with a two-layer construction of permanent magnets used in motors (Patent Application No. 7-134023). The said prior art rotor 3 comprises iron rotor proper 3a embedded with four sets of permanent magnets 8, 9 that are arranged on rotor 3a in two layers for each pole with a gap separating the layers. Each set of permanent magnets 8, 9 are placed in proximity to each other with alternating N and S poles, and furthermore permanent magnets 8, 9 with a two-layer relationship are constructed so that the polarity along the outer periphery is the same. Permanent magnets 8, 9 closer to the outer periphery and permanent magnets 8, 9 closer to the inner periphery are all shaped in an arc of which a convex side faces to the rotor center. Outer permanent magnet 8 and inner permanent magnet 9 forming a two-layer relationship are arranged to be parallel to each other and separated by a set gap.

Furthermore, each of the aforesaid permanent magnets 8, 9 are made of the same magnetic material with the same thickness in the radial direction.

With rotor 3 wherein outer permanent magnets 8 and inner permanent magnets 9 are embedded in two layers with a gap separating the layers, the interaction between the rotating magnetic field created by a group of windings 10 on stator 2 and the magnetic fields created by permanent magnets 8, 9 generates a magnet torque. A reluctance torque is also generated by the flux paths which are created by the aforesaid rotating magnetic field along the surface of rotor 3a and in the gap between inner and outer permanent magnets 8, 9. The said magnet torque and reluctance torque create a resultant torque which rotates the rotor 3 in direction R.

Fig. 4 shows the results of a magnetic field analysis when an opposing magnetic field is applied to rotor 3 by stator 2. In the figure, (1) the magnetic flux density of permanent magnets 8 closer to the outer periphery is higher than that of permanent magnets 9 closer to the inner periphery; (2) the magnetic flux density along the cross-section of the arc is higher at the two ends than at the center for any one permanent magnet 8 or 9 regardless of the layer or pole; and (3) for any one permanent magnet 8 or 9 regardless of the layer or pole, the magnetic flux along the surface closer to the outer periphery of the rotor is higher than the magnetic flux along the surface closer to the inner periphery of the rotor.

## Problem to be Solved by the Invention

With the afore-described construction, as described above in reference to the results of the analysis shown in Fig. 4, when an opposing magnetic field is applied to rotor 3 by stator 2, (1) the magnetic flux density of outer permanent magnets 8 becomes higher than that of inner permanent magnets 9; (2) the magnetic flux density along the cross-section of the arc is higher at the two ends than at the center for any one permanent magnet 8 or 9 regardless of the layer or pole; and (3) for any one permanent magnet 8 or 9 regardless of the layer or pole, the magnetic flux along the surface closer to the outer periphery of the rotor is higher than the magnetic flux along the surface located closer to the rotor center.

This means that, in permanent magnets with a multi-layer construction, if permanent magnets 8 that are positioned closer to the outer periphery of the rotor are made of the same magnetic material as permanent magnets 9 located closer to the inner periphery of the rotor or if different magnetic materials are not used among individual permanent magnets 8, 9 in the different layers and poles, a problem arises with susceptibility to demagnetization.

A conceivable means of solving this problem is to construct permanent magnets 8, 9 using magnetic materials with a high coercivity, but if the entire magnets are simply constructed using magnetic materials

with a high coercivity, the properties of the motor will suffer since increasing the coercivity of a common permanent magnet such as a ferrite magnet will reduce the residual magnetic flux density.

The present invention solves the aforesaid problem and provides a permanent magnet embedded rotor that is less susceptible to demagnetization and a degradation in properties.

#### Means for Solving the Problem

With the permanent magnet embedded rotor of the present invention, embedded in the rotor is a plurality of sets of permanent magnets arranged, in the radial direction of the rotor, in two or more separated layers for each pole. Each of the said permanent magnets is shaped in an arc of which a convex side faces to the rotor center. In the said multi-layer arrangement of permanent magnets, the coercivity of the permanent magnets located closer to the outer periphery of the rotor is higher than that of the inner permanent magnets located closer to the inner periphery of the rotor, making demagnetization less likely to occur.

#### Modes for Practicing the Invention

With the present invention, embedded in the rotor is a plurality of sets of permanent magnets arranged, in the radial direction of the rotor, in two or more separated layers for each pole. Each permanent magnet is shaped in an arc of which a convex side faces to the rotor center. In a two-layer arrangement of permanent magnets, the coercivity of the permanent magnets located closer to the outer periphery of the rotor is higher than that of the inner permanent magnets located closer to the inner periphery of the rotor.

With the present invention, embedded in the rotor is a plurality of sets of permanent magnets arranged, in the radial direction of the rotor, in one or more separated layers for each pole. Each permanent magnet is shaped in an arc of which a convex side faces to the rotor center, and for each permanent magnet, the coercivity of the surface located closer to the outer periphery of the rotor is higher than the coercivity of the surface located closer to the inner periphery of the rotor.

With the present invention, embedded in the rotor is a plurality of sets of permanent magnets arranged, in the radial direction of the rotor, in one or more separated layers for each pole. Each permanent magnet is shaped in an arc of which a convex side faces to the rotor center, and with each permanent magnet, the coercivity at the two ends is higher than the coercivity at the center.

With the present invention, embedded in the rotor is a plurality of sets of permanent magnets arranged, in the radial direction of the rotor, in two or more separated layers for each pole. Each permanent magnet is shaped in an arc of which a convex side faces to the rotor center, and with each permanent magnet, the coercivity at the two ends is higher than the coercivity at the center while at the same time, in a multi-layer arrangement of permanent magnets, the coercivity of the permanent magnets located closer to the outer periphery of the rotor is higher than that of the inner permanent magnets located closer to the inner periphery of the rotor.

With the present invention so constructed, when the stator applies an opposing magnetic field to the rotor, demagnetization is less likely to occur since the portion of each permanent magnet with a high magnetic flux density is constructed of a magnetic material with a high coercivity while at the same time, since only those portions of a permanent magnet with a high demagnetization magnetic flux density are constructed of a magnetic material with a high coercivity, the degradation in properties is kept to a minimum. Hence the present invention provides a permanent magnet embedded rotor that is less susceptible to demagnetization and a degradation in properties.

## Embodiments

Embodiments of the present invention are described next with reference to figures.

### Embodiment 1

Embodiment 1 is illustrated by Fig. 1 and Fig. 2.

Rotor 13 comprises four sets of permanent magnets 18, 19 which are embedded in rotor proper 13a made of iron with each pole consisting of two separated layers arranged in the radial direction of the rotor. Each set of permanent magnets 18, 19 is located in proximity to each other with alternating S and N poles. Permanent magnets 18, 19 with a two-layer relationship are constructed so that the polarity along the outer periphery is the same. Outer permanent magnets 18 and 19 and inner permanent magnets 18 and 19 are all shaped in an arc of which a convex side faces to the rotor center. Outer permanent magnets 18 and inner permanent magnets 19 forming a two-layer relationship are arranged to be parallel with a set gap separating the two.

Furthermore, for any one permanent magnet regardless of the layer or pole, the two ends 18c, 19c along the cross-section of the arc are made of a magnetic material with a higher coercivity than the centers 18d, 19d along the cross-section of the arc while at the same time, for any pole, permanent magnets 18b located closer to the outer periphery of the rotor are made of a magnetic material with a higher coercivity than permanent magnets 19b located closer to the inner periphery of the rotor.

Stator 12 is provided with a plurality of teeth with windings 20 disposed between the said teeth 14 so that a rotating magnetic field is generated by running an alternating current through the said windings 20.

As stated earlier, Fig. 4 shows the results of a magnetic field analysis at one point with an opposing magnetic field applied to rotor 3 by stator 2. In Fig. 4, the magnetic flux that is generated by teeth 4 of stator 2 enters rotor 3 from its outer perimeter, and once inside the rotor, passes sequentially through outer permanent magnet 8, inner permanent magnet 9, the yoke located along the rotor inner diameter, then back through inner permanent magnet 9, outer permanent magnet 8 and back to stator 2. When this occurs, as the figure shows, (1) the magnetic flux density of permanent magnets 8 located closer to the outer periphery is higher than that of permanent magnets 9 located closer to the inner periphery, and (2) the magnetic flux density along the cross-section of the arc is higher at the two ends 8c, 9c than at the centers 8d, 9d for any one permanent magnet 8 or 9 regardless of the layer or pole.

This means that if permanent magnets 8 located closer to the outer periphery are made of the same magnetic material as permanent magnets 9 located closer to the inner periphery as in the prior art or if the same magnetic material is used for each permanent magnet in the different layers layer or poles, demagnetization will be likely to occur.

As stated earlier, with the present invention, each permanent magnet, regardless of the layer or pole, is constructed so that the two ends 18c, 19c along the cross-section of the arc-shaped permanent magnet are made of a magnetic material with a higher coercivity than that of the magnetic material used for the centers 18d, 19d along the cross-section of the arc-shaped permanent magnet while at the same time, for each pole, permanent magnets 18b located closer to the outer periphery are made of a magnetic material with a higher coercivity than that of the magnetic material used for permanent magnets 19b located closer to the inner periphery so as to provide a permanent magnet embedded rotor that is less susceptible to demagnetization.

Furthermore, since magnetic materials with a high coercivity are used only where the demagnetization magnetic flux density is high, the degradation in properties is minimized.

### Embodiment 2

If attention is focused on individual permanent magnets in the different layers and poles, it will become evident from Fig. 4 that the magnetic flux along the surfaces 8, 9 closer to the outer periphery of the rotor is higher than the magnetic flux along the surfaces 8,9 located closer to the inner periphery. This means that a permanent magnet embedded rotor with a minimal degradation in properties and less susceptibility to demagnetization can be provided if, as Fig. 3 shows, each permanent magnet in any layer or pole is constructed to have a higher coercivity along magnet surfaces 38e, 39e located closer to the outer periphery than the magnet surface 38f, 39f located closer to the inner periphery.

#### Effects of the Invention

As afore-described, according to the invention described in claim 1 of this application, because a magnetic material with a higher coercivity is used for the outer permanent magnet, a beneficial effect of lesser susceptibility to demagnetization is provided when an opposing magnetic field is applied by the stator to each of the permanent magnets. Furthermore, since magnetic materials with a high coercivity are used only where the demagnetization magnetic flux density is high, the degradation in properties is minimized.

Also, with the invention described in claim 2, since a high [coercivity] magnetic material is used for the outer surface of the permanent magnet, there is less susceptibility to demagnetization.

Also, with the invention described in claim 3, since a high [coercivity] magnetic material is used for the two ends of the arc, there is less susceptibility to demagnetization.

Also, with the invention described in claim 4, since the magnetic force of the outer magnet that is embedded is large and furthermore the magnetic force of the two ends of the magnet is large, there is less susceptibility to demagnetization.

#### Brief Explanation of the Figures

Fig. 1 Sectional view of embodiment 1 of the present invention

Fig. 2 Sectional view of a portion thereof

Fig. 3 Sectional view of a portion of embodiment 2 of the present invention

Fig. 4 Sectional view of a magnetic field analysis of a permanent magnet embedded rotor

Fig. 5 Sectional view of a conventional motor

#### Description of the Reference Numbers

13 Rotor

13a Rotor proper

18 Permanent magnet

19 Permanent magnet

#### Fig. 1

3: Rotor

3a: Rotor proper

8, 9: Permanent magnets